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Simulation of the hydraulic performance of Highway Filter Drains through Laboratory Models and Stormwater Management Tools

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Abstract

Road drainage is one of the most relevant assets in transport infrastructure due to its inherent influence on traffic management and road safety. Highway Filter Drains (HFD), also known as “French Drains”, are the main drainage system currently in use in the UK throughout 7,000 km of its strategic road network. Despite being a widespread technique across the whole country, little research has been done on their design considerations and their subsequent impact on their hydraulic performance, representing a gap in the field. Laboratory experiments have been proven to be a reliable indicator for the simulation of the hydraulic performance of Stormwater Best Management Practices (BMPs). In addition to this, Stormwater Management Tools (SMT) have been preferentially chosen as a design tool for BMPs by practitioners from all over the world. In this context, this research aims to investigate the hydraulic performance of HFD by comparing the results from laboratory simulation and two widely used SMT such as the US EPA’s StormWater Management Model (SWMM) and MicroDrainage®. Statistical analyses were applied to a series of rainfall scenarios simulated, showing a high level of accuracy between the results obtained in laboratory and using SMT as indicated by the high and low values of the Nash-Sutcliffe and R^2 coefficients and Root Mean Square Error (RMSE) reached, which validated the usefulness of SMT to determine the hydraulic performance of HFDs.

Keywords: Highway Filter Drains (HFD); Low Impact Development (LID); Rainfall-runoff simulation; Sustainable Drainage Systems (SuDS); Transport Infrastructure; Water Sensitive Urban Design (WSUD).

1. Introduction

The UK has one of the densest road networks in Europe, consisting of nearly 1.8 km road/km^2 land area (Nicodeme et al. 2012) and more than 300 billion vehicle miles in 2014 (UK Department of Transports 2015). Hence, to ensure safety, road condition and environmental protection (Coupe et al. 2015), Filter Drains (FDs) (Highway Filter Drains -HFDs- when used in Highways/Motorways), also known as “French Drains”, have been implemented and maintained in 7,000 km of the UK’s Strategic Road Network (SRN). HFDs catch the runoff, safely removing it from the carriageway, and treat the pollutants washed off from the road whilst reducing the runoff peak-flow before discharging into natural watercourses downstream or conventional drainage systems (Woods-Ballard et al. 2015).

The importance of FDs in other European countries outside Great Britain can be measured by the research carried out in the Republic of Ireland by Bruen et al. (2006) and Desta et al. (2007), where more than 40% of dual carriageways and motorways use FDs as their main drainage asset. Spain has also implemented the use of FDs as a Sustainable Drainage System (SuDS) instead of a more conventional road technique as in the UK, having achieved promising results as shown in Castro-Fresno et al. (2013), Andrés-Valeri et al. (2014) and Sañudo-Fontaneda et al. (2014b).

Design considerations for Road FDs in the UK can be obtained from the “Design Manual for Roads and Bridges” (DMRB-UK 2004). The manual specifies that highway drainage systems should be designed in order to be fully capable of catching runoff produced by high-intensity rainfall events over a few minutes with return periods between 1 and 5 years.

Despite the importance of HFD to drainage highways, there is little research carried out up to date. Stylianides et al. (2016) focused on the study of Ground Penetration Radar (GPR) technologies to assess HFD condition onsite. However, there was no relationship stablished between HFD condition and hydraulic performance (infiltration rates and hydrographs, rainfall intensities, etc.). Coupe et al. (2015; 2016) pointed out the need for developing both laboratory and field studies in order to identify the main variables affecting HFD hydraulic performance. They also linked hydraulic performance with the structural performance of HFDs. This study, alongside Sañudo-Fontaneda’s et al. (2016) first attempt to link stormwater management tools with HFD hydraulic performance, was supported by and earlier research published by Ellis and Rowlands (2007). They showed the importance of HFDs and identified the main problems affecting them such as clogging due to sedimentation. No in depth relationship was established then between hydraulic performance and clogging effects. Furthermore, Norris et al. (2013) found out that mechanisms involved in pollution attenuation on SuDS gravel columns used as drainage systems in roads had been poorly addressed so far, contributing to improve the understanding of their water quality performance. However, other international researches undertaken on Stormwater Best Management Practices (BMP) similar to HFD are available and support the identification of the main needs to advance research in this area. Thomas et al. (2015), Haselbach et al. (2015) and Freimund et al. (2015) investigated the long-term water quality performance of Media Filter Drain (MFD) in roads by means of accelerated tests in the laboratory. Witthoeft et al. (2014) developed methods to assess the infiltration rates of BMPs used in roads, including HFDs. Other works by Motsinger et al. (2016) and Bhattarai et al. (2009) focused on the water quality treatment capacities of vegetated strips with similar structures than those of a HFD. Nevertheless, none of these researches evaluated described the hydraulic performance of a HFD, studied its performance under different rainfall intensities and storm durations and linked them to the results obtained by using stormwater management tools.Laboratory experiments based upon the simulation of rainfall events and runoff volumes have been successfully used across the world to model real and varying conditions in the field, including the challenge induced by Climate Change (Golroo and Tighe 2012). This type of research based on experimentation and heavily controlled surrounding conditions allow researchers simulating and modelling the hydraulic performance of Stormwater Best Management Practices (BMPs), known as SuDS in the UK (Fletcher et al. 2015), up to a high level of accuracy. There are many examples of successful researches carried out to simulate the hydraulic performance of BMPs in laboratory. Research on Permeable Pavement Systems (PPS) (Rodriguez-Hernandez et al. 2012; Sañudo-Fontaneda et al. 2013; Sañudo-Fontaneda et al. 2014c; Rodriguez-Hernandez et al. 2016; Huang et al. 2016) and grassed areas and green roofs (Deletic 2005; Alfredo et al. 2016) are some of the most commonly studied SuDS in the literature.

In order to investigate the hydraulic performance of HFD as a previous step before validating the results in the field, laboratory models of HFD were developed and tested under varying scenarios of rainfall intensities and storm durations. Further work was orientated towards the area of replicating the laboratory conditions through stormwater simulations, with the aim of comparing the results achieved through them with those obtained in laboratory. For this late purpose, computational programmes such as the US EPA’s StormWater Management Model (SWMM) and MicroDrainage® were selected, due to their condition as some of the most recognised tools for stormwater management design worldwide (Coupe et al. 2016;

Sañudo-Fontaneda et al. 2016). SWMM is one of the most used tools due to its particular characteristics containing specific modules for the simulation of BMPs/SuDS, such as the Low Impact Development (LID) Control Editor (Rossman 2010), where FDs are included as a technique. Moreover, SWMM is a free rainfall and runoff-modelling tool available (Jato-Espino et al. 2016a; Sañudo-Fontaneda et al. 2016) and it allows the simulation of small-scale watersheds (Lee et al. 2010; Niazi et al. 2017). As a demonstration of their use to design and simulate BMPs, several researches have been conducted using SWMM as the stormwater management design tool (Zhang and Duo 2015; Jato-Espino et al. 2016b), including some studies focused on validating its application through both field (Rosa et al. 2015; Cipolla et al. 2016; Krebs et al. 2016) and laboratory experiments (Palla and Gneco 2015). On the other hand, MicroDrainage® is the preferred stormwater management drainage design tool in the UK industry, including specific modules that contain SuDS (Hubert et al. 2013). FDs are therefore included as part of the package and their hydraulic performance can be modelled under varying conditions of rainfall events and runoff volumes both in SWMM and MicroDrainage®.

The main aim of the research presented in this article is, therefore, the investigation of the hydraulic performance of HFD using both laboratory and modelling tools. This article intends to clarify the understanding of HFD performance and support the use of stormwater management tools as part of research methodologies, in order to promote their application to predict the potential impact of drainage systems when designing urban water resources planning strategies. This later objective will need to be validated in the field in future researches.

2. Materials and Methods

2.1. Materials used in the laboratory experiments

The material used in the laboratory simulations was obtained from real Type B aggregate of clean igneous Granodiorite characteristics, which is used to refurbish highway FDs in the UK's SRN, and therefore complies with the UK Highways Agency Manual of Contract Documents for Highway Works (MCDH 2009) and BS EN 13242 requirements (BSI 2006). The Particle Size Distribution (PSD) of the aggregate is shown in Table 1.

Table 1. PSD of the Type B aggregate used in the laboratory simulation and its comparison with the specifications in the MCDH (2009) and BS EN 13242 (BSI 2006).

BS Sieve Size (mm)	% Passing (Laboratory)	% Passing (Specifications)
80	100	100
63	100	98 – 100
40	93	85 – 99
20	11	0 – 20
10	1	0 – 5

2.2. Experimental methodology

The experimental methodology of this research was divided into 3 main areas. Firstly, the experiments carried out in the laboratory and the simulation methodology are described in detail. Secondly, the stormwater design management tools used in the research are presented with the specific features utilised in the investigation. Finally, the statistical analyses that determine the accuracy of the comparison between the results obtained in laboratory and the results produced by the simulations on the stormwater design tools are delivered.

2.2.1. Laboratory simulations

Special rigs of 21.5 cm x 21.5 cm x 65.0 cm dimensions were tailored made out of plate-glass material for visual analysis of the infiltration performance of the columns of gravel (see Figure 1). Four of these rigs were used to obtain enough reliability in the subsequent statistical analyses.

The pipe that is usually installed in HFD was deliberately avoided in this study, in order to focus the analysis on the hydraulic performance of the porous media represented by the standardised Type B aggregate. This decision enables describing the physical equations underpinning the hydraulic processes in the HFD accurately. The pipe that serves as an underdrain in HFDs is governed by different processes and it is usually related to the Colebrook-White formula (Colebrook and White 1937). The Darcy’s law (Whitaker 1986) that acts as a framework for the hydraulic behaviour of porous media with the characteristics of the materials used in the HFD (see Table 1) and under non-saturated conditions, which are typical of the simulations carried out in this research, were applied under the assumption of steady-state flow through the aggregate. Therefore, the physical performance beneath the whole infiltration process is defined by the Navier-Stokes equations (Novak et al. 2010) due to the high void ratio (commonly over 40%) of the material, which avoids saturation during the experiments (Sansalone et al. 2008; Charbeneau et al. 2010; Rodriguez-Hernandez et al. 2012; Sañudo-Fontaneda et al. 2013; Sañudo-Fontaneda et al. 2014a; Sañudo-Fontaneda et al. 2014c).

Fig. 1 Detail of the laboratory HFD model and the rainmaker.

The input parameters for this laboratory study were the rainfall intensities, storm durations and type of aggregate utilised, whilst the output parameter was the infiltration rates and accumulated volumes described by the hydrographs of performance. Infiltration rates were measured by collecting the outflow from the experiments by using a sample collector underneath the laboratory rigs in periods of 1 minute during the development of the test. Rainfall intensity was simulated by the use of a tailored made rainmaker. The inflow was controlled at any time through the use of a flowmeter connected to a water intake and the rainmaker. Every storm event was simulated by maintaining the same intensity thorough the whole experiment for each rainfall intensity studied.

The hydraulic performance of FD was characterised through the simulation of 9 different storm scenarios obtained from the combination of 3 high rainfall intensities (100, 200, 400 mm/h), with their correspondent runoff flows in a highway, and 3 short-duration storm events (5, 10 and 15 minutes) as required in the design criteria specified in the DMRB-UK (2004). Neither sediments nor pollutants were added to the laboratory rigs used to replicate the gravel columns embedded in the HFD in order to avoid the disturbance on the hydraulic performance of the gravel that conforms the HFD. Therefore, just tap water was used in the experiments.

Sañudo-Fontaneda et al. (2016) partially described the relation between the simulation of direct rainfall over the rigs and their correspondence with the runoff volume reaching the FD from the carriageway for the very same rainfall intensity. This process of early comparison is required to understand the subsequent modelling of the 9 scenarios in the stormwater design management tools, because it will influence the receiving area of the direct rainfall and the receiving area of the runoff produced by it, which are entirely different. In order to clarify the calculations, the use of the Rational Method for small catchments (Nash 1958), which fits perfectly the description of a transport infrastructure such as a road (Woods-Ballard et al. 2016; DMRB-UK 2004), was selected as the equation to control the transformation from rainfall intensity, raining down over a certain area, into runoff volume entering the FD (Coupe et al. 2016; Sañudo-Fontaneda et al. 2016). Under these premises, Table 2 has been prepared to understand the transformation from the volumes of direct rainfall and the volumes of runoff for a contribution area defined by 2 carriageways of 3.0 m width and a hard-shoulder of 1.8 m width. Since the length of the laboratory-simulated rigs was 0.215 m, this contribution area amounted up to 1.677 m^2.

Table 2. Surface runoff flow for a 100 m length HFD produced by the simulated rainfall events for a contribution area consisting on 2 carriageways and a hard-shoulder (7.8 m width).

Rainfall intensity directly simulated over the laboratory rigs (mm/h)	**Flow simulated over the laboratory models for the rig's surface (0.046 m^2) (L/min)**	**Equivalent rainfall intensity for the flow simulated, having a contribution area defined by the 2 carriageways + hard shoulder (1.677 m^2) (mm/h)**
100	0.070	2.5
200	0.140	5
400	0.280	10

The application of the Rational Method (Woods-Ballard et al. 2016; DMRB-UK 2004) considering the flow simulated over the laboratory models as the runoff volume discharged from a contribution area of 1.677m^2 enabled the direct rainfall simulated over the rigs to be translated into the direct rainfall corresponding to the real length of 2 carriageways and a hard-shoulder, which are a common standard in UK highways. Therefore, the last column in Table 2 provides the values of that rainfall intensity (2.5, 5 and 10 mm/h), which are considered of great interest for road designers as they are representative of common rainfall event in the West Midlands, the area of the UK where the research was conducted. In addition, a rainfall event of 10 mm/h and 15 minutes of storm duration corresponds to 11 months of return period in the West Midlands (Alfredo et al. 2010), achieving the year of return period required for the FD to cope with the design rainfall event and runoff volume specified by the DRMB-UK (2004).

2.2.2. Stormwater Design Management Tools

The same rainfall scenarios described in the laboratory experiments were simulated both in the Stormwater Management Model (SWMM) and MicroDrainage®. SWMM is a widely used rainfall-runoff piece of software that simulates diverse phenomena associated with urban hydrology: continuous and discrete storm events, runoff generation, water routing, overflow discharge and reservoir storage (Huber et al. 1988). Furthermore, it enables modelling the impact of different SuDS on water quantity and quality through its LID Control Editor (Rossman 2010). Although HFD are not explicitly included among them, they can be assimilated to infiltration trenches, which are one of the eight types of SuDS available in SWMM.

The scaled laboratory conditions were replicated in SWMM by defining a sub-catchment of 0.078 ha (100 m length by 7.8 m width), which represented the contributing area flowing to the HFD. Three different uniform storms were designed to simulate the equivalent rainfall intensities listed in Table 2, including a 1-minute time step to reproduce the real-time testing used in laboratory. Moreover, the cross-section of the HFD was characterized through a 650 mm thick layer with a porosity of 0.4. The seepage rate was set at 0, since this parameter concerns the infiltration capability of the soil below the HFD. All these parameters were fixed by both the characteristics of the materials and the conditions under which the laboratory tests were conducted. Hence, the only parameters which were variable and, therefore, subject to calibration were those referred to the drain system of the rigs. None of the specifications included in the SWMM "Drain Advisor", which consider the existence of impermeable bottoms, slotted pipes or fully saturation, replicated the outflow conditions of the tests. Drain systems are characterized in SWMM through two parameters: flow coefficient and flow exponent. These parameters are performance-based rather than design-based and its combination determines the height above the bottom of the LID unit storage layer and how its volumetric flow rate varies with the height of saturated media above it (Rossman 2010). The calibration of simulations proved that a ratio 1:6 ratio between flow exponent and flow coefficient provided the best fit to the drain characteristics of the test rigs. In particular, the best fit for the flow exponent was found to be in the range of 1 and 3, from more to less conservative. The results of the calibration demonstrated that a flow exponent of 1.75 and a flow coefficient of 10.50 was the best combination to keep a balance between conservatism and accuracy.

The DrawNet suite within MicroDrainage®, which is the UK industry standard drainage modelling tool, was also used to simulate the HFD (Hubert et al. 2015; Lashford et al. 2014). The software enabled the design and simulation of both piped and SuDS drainage systems, which included the modelling of a HFD. The HFD was designed using the equivalent parameters and contributing area as used in SWMM. Each design storm was subsequently simulated in the software package, based on the rainfall monitored in the laboratory, and the outputs compared to evaluate the performance of the FD.

In a second step, the results were scaled up from 0.215 up to a 100 m length, in order to be ready for comparison with the results obtained from the management tools, which have the limitation of not providing results for very small catchments like the one simulated in the laboratory. The flow values obtained at the discharge point of the FD are shown below in Table 3 and were obtained after applying the Rational Method for small catchments (Woods-Ballard et al. 2016; DMRB-UK 2004).

Table 3. Runoff flow value calculated as the volume of runoff entering the simulated 100 m length FD from the equivalent contribution area consisting on the 2 carriageways and the hard-shoulder (7.8 m width).

Rainfall intensity raining down the equivalent contribution area scaled up to 100 m length of FD and 2 carriageways + hard shoulder (780 m^2) (mm/h)	**Surface runoff volume produced by the intensities raining over the equivalent contribution area considered in the first column (L/s)**
2.5	0.54

5	1.09
10	2.17

2.2.3. Statistical analyses

Three goodness-of-fit coefficients were considered to validate the accuracy of the comparison between the laboratory simulations and the results obtained from the modelling of the same 9 scenarios using SWMM and MicroDrainage®. This course of action was in line with the recommendations made by Jain and Sudheer (2008), who suggested that the use of a sole goodness-of-fit measure can be misleading. Therefore, the Nash-Sutcliffe (Nash and Sutcliffe 1970) and the R^2 (Hirsch et al. 1993) coefficients and the Root Mean Square Error (RMSE) (Chai and Draxler 2014) were chosen for their reliability in previous researches. In addition, inferential statistical techniques were applied to verify the absence of differences between the hydrographs obtained for both the laboratory and computer models. Thus, parametric (known distribution) or non-parametric (unknown distribution) tests were used depending on whether the hydrographs followed normal distributions or not, according to the Shapiro-Wilk test (Shapiro et al. 1965). A significance level of 0.05 was chosen for statistical testing.

3. Results and Discussions

The results of all experiments carried out in the laboratory models and the simulations developed in the stormwater management tools (SWMM and MicroDrainage®) are presented and discussed in this point. The main areas for the interpretation and discussion of these results are the hydrographs of performance obtained from the laboratory simulations and the design tools. Finally, the results from the statistical analyses are described and discussed as a support for the hydrographs of performance.

3.1. Hydraulic characterisation of the FD in the laboratory

The characterization of the performance of FD was carried out through the laboratory simulation of the different 9 storm scenarios, so that each scenario is represented by the hydrographs obtained as a result of the outflows measured beneath the laboratory rigs in periods of 1 minute.

The average hydrographs obtained from the rigs tested in laboratory (Av. Rigs) were compared with those determined from the simulations of the 9 different storm scenarios with the SWMM and the

MicroDrainage® tools as represented in Figure 2, dividing the analysis of the hydrographs into the three different storm event durations (5, 10 and 15 minutes). The mere visual inspection of these plots demonstrated the excellent fit between the hydrographs obtained in laboratory and those determined using stormwater tools. Furthermore, the simulations run with SWMM and MicroDrainage® resulted in more conservative hydrographs generally (slight overestimation of the discharge of HFD), which involves being on the safe side in terms of design.

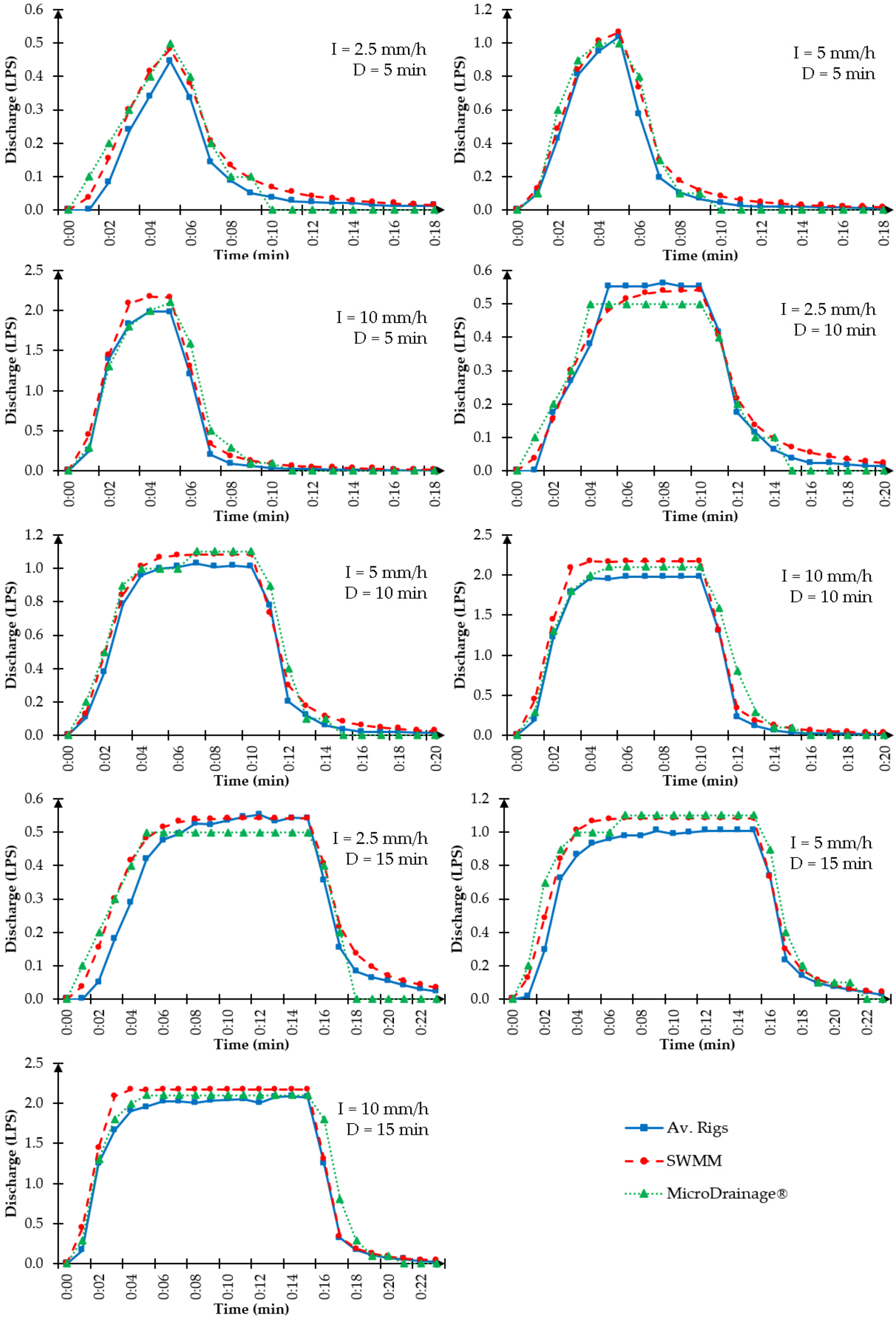

Fig. 2 Hydrographs for a 100 m length HFD extrapolated from the results obtained for the laboratory models

3.2. Statistical analyses

The statistical analyses include the main coefficients that allow to determine the validity of the models obtained using the SMT through their comparison with the laboratory simulations. For this reason, the Nash-Sutcliffe and R^2 coefficients and the Root Mean Squared Error (RMSE) were calculated for all the different scenarios of rainfall as shown in Table 4. Overall, the results revealed that the higher the rainfall intensity, the better the level of accuracy of the laboratory models in comparison with the simulations obtained in SWMM and MicroDrainage®.

The Nash-Sutcliffe coefficients validated the methodology showing very high values in the region of 0.88 and 0.99 for both SWMM and MicroDrainage® when comparing them with the laboratory simulations. The R^2 coefficient reached high values as well, being always above 0.97 in all storm scenarios simulated with both design management tools. Furthermore, the values of RMSE achieved were generally below 10% of the discharge peaks for both SWMM and MicroDrainage®, which ensured that the differences in the amount of volume produced between the laboratory and computer hydrographs were minimal.

Table 4. Statistical analyses conducted using the Nash-Sutcliffe and R^2 coefficients and the RMSE

Goodness-of-fit measure	***Stormwater Management Tool (SMT)***	***Storm duration (minutes)***								
		5			10			15		
		Rainfall Intensity (mm/h)								
		2.5	5	10	2.5	5	10	2.5	5	10
Nash-Sutcliffe Coefficient	***SWMM***	0.92	0.97	0.98	0.98	0.98	0.97	0.95	0.96	0.97
	MicroDrainage®	0.86	0.95	0.97	0.95	0.97	0.97	0.92	0.91	0.97
R^2 Coefficient	***SWMM***	0.98	0.99	1.00	0.99	1.00	1.00	0.97	0.99	0.99
	MicroDrainage®	0.94	0.97	0.97	0.96	0.98	0.98	0.92	0.96	0.98
Root Mean Square Error (RMSE)	***SWMM***	0.04	0.06	0.11	0.03	0.06	0.15	0.05	0.09	0.15
	MicroDrainage®	0.05	0.08	0.13	0.05	0.08	0.17	0.06	0.13	0.17

The hydrographs illustrated in Figure 2 were evaluated using statistical techniques, in order to validate the absence of differences between the laboratory and computer results. Almost all the p-values obtained after checking normality for the datasets behind the hydrographs were below 0.05, which suggested that the samples under study had to be analysed using non-parametric tests.

Therefore, the Kruskal-Wallis test was applied to check the hypothesis that the three types of hydrographs (Av. Rigs, SWMM and MicroDrainage®) were not significantly different. The p-values shown in Table 5 confirmed this hypothesis, since they were above the significance level in all cases. Consequently, the

Mann-Whitney test was used to prove the similarity between hydrographs derived from the laboratory and computer simulations, as well as that between the results obtained with SWMM and MicroDrainage®. Again, the values listed in Table 5 in relation to this test demonstrated that the differences in each pairwise comparison were not significant (p-values>0.05). In overall terms, these results proved the high accuracy of computer-based models to replicate the hydraulic performance of HFDs as tested in laboratory.

Table 5. Non-parametric comparative analysis of the hydrographs obtained for the laboratory and computer models

Storm scenario		***Kruskal-Wallis***	***Mann-Whitney***		
Storm duration (minutes)	***Rainfall Intensity (mm/h)***	***Av. Rigs*SWMM* MicroDrainage®***	***Av. Rigs* SWMM***	***Av. Rigs* MicroDrainage®***	***SWMM* MicroDrainage®***
5	2.5	0.300	0.231	0.423	0.204
	5	0.223	0.343	0.204	0.148
	10	0.349	0.226	0.470	0.257
10	2.5	0.663	0.880	0.447	0.440
	5	0.667	0.263	0.870	0.695
	10	0.336	0.162	0.649	0.312
15	2.5	0.327	0.503	0.460	0.129
	5	0.169	0.087	0.153	0.419
	10	0.077	0.057	0.202	0.102

4. Conclusions

The main conclusions reached in this research conducted as an international collaborative effort are as follows:

- Laboratory simulations have proven to be an accurate tool to determine the hydraulic performance of FDs under varying scenarios represented by a varying range of rainfall intensities and storm durations.
- The use of stormwater design management tools can be validated through the models of performance obtained in the laboratory experiments to provide decision-makers with an accurate and reliable means of estimating the potential impact of FDs on urban drainage.
- The methodology presented in this article has been validated through the comparison of laboratory-simulated experiments, stormwater design management tools using statistical analyses, including the Nash-Sutcliffe and R^2 coefficients and the Root Mean Square Error (RMSE).

- Small-scale laboratory simulation models require to be scaled-up adequately by using the appropriate mathematical equations, in order to be realistic and to be adapted to real scenarios of rainfall and real contribution areas.

As a final conclusion to this article, the authors of this research would like to indicate the future research lines that are recommended to achieve full validation of these models in the field.

- A full-scale study in the field is recommended to further validate the models obtained in the laboratory simulations and the results achieved using SWMM and MicroDrainage®.
- A full-scale study where important parameters such as the flow of water entering the FD and the real contribution area are fully monitored is recommended, in order to not lose the potential for comparison with the models obtained in this research. The heterogeneity of conditions in the field required the isolation of parameters and variables that may disturb the comparisons and, therefore, they may inadequately describe the scenario and would be not acceptable for comparison and/or application of the models obtained in laboratory and through the management tools.

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